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ABSTRACT

This booklet was prepared by practicing oceanographers to help college students in their search for professional direction. The booklet: (1) points out some frontiers of current research; (2) describes five major subfields of oceanography (marine geology and geophysics, oceanographic engineering, physical oceanography, chemical oceanography, and biological oceanography); (3) outlines the necessary undergraduate preparation; (4) suggests how to approach graduate work; and (5) discusses career prospects. (JN)

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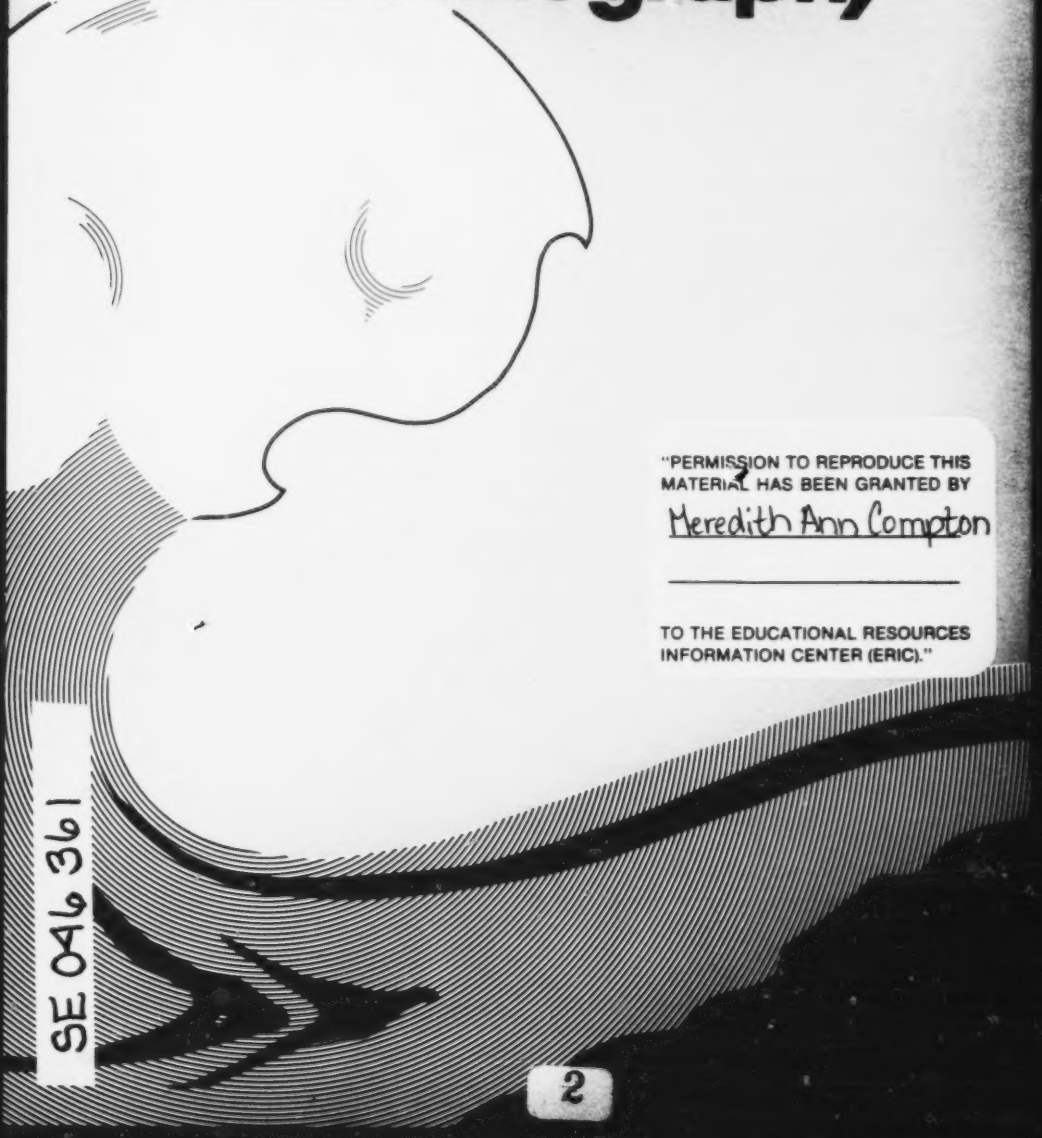
careers in Oceanography



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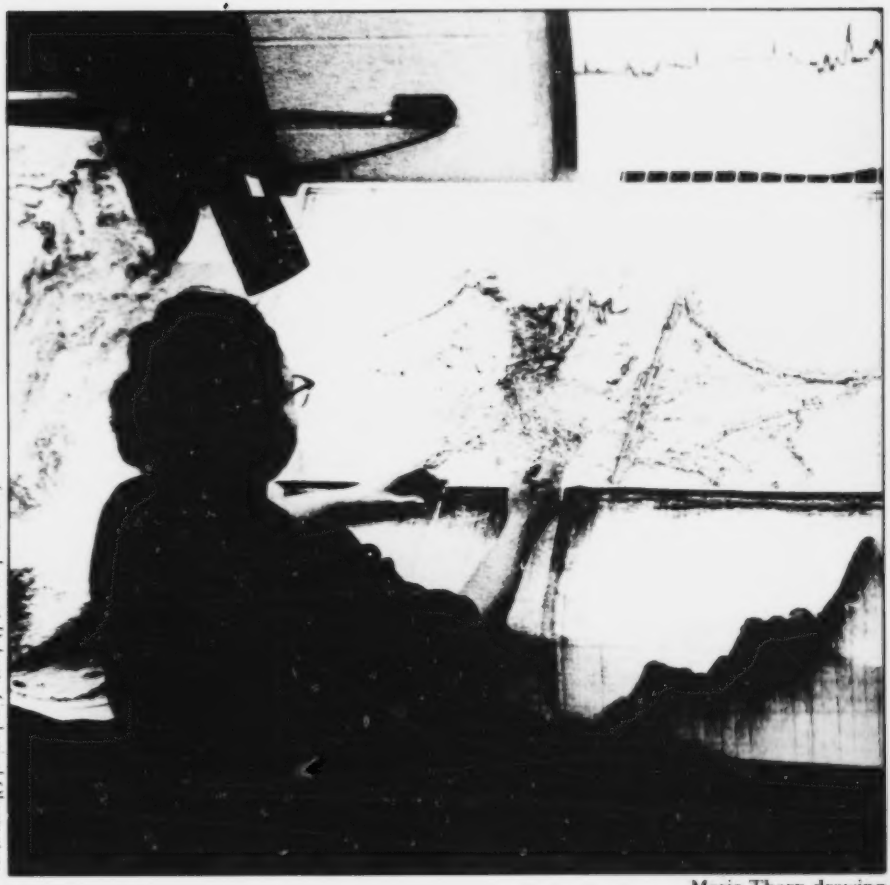

Courtesy Lamont-Doherty Geological Observatory

Marie Tharp drawing
ocean floor physiography
from echo sounding records.

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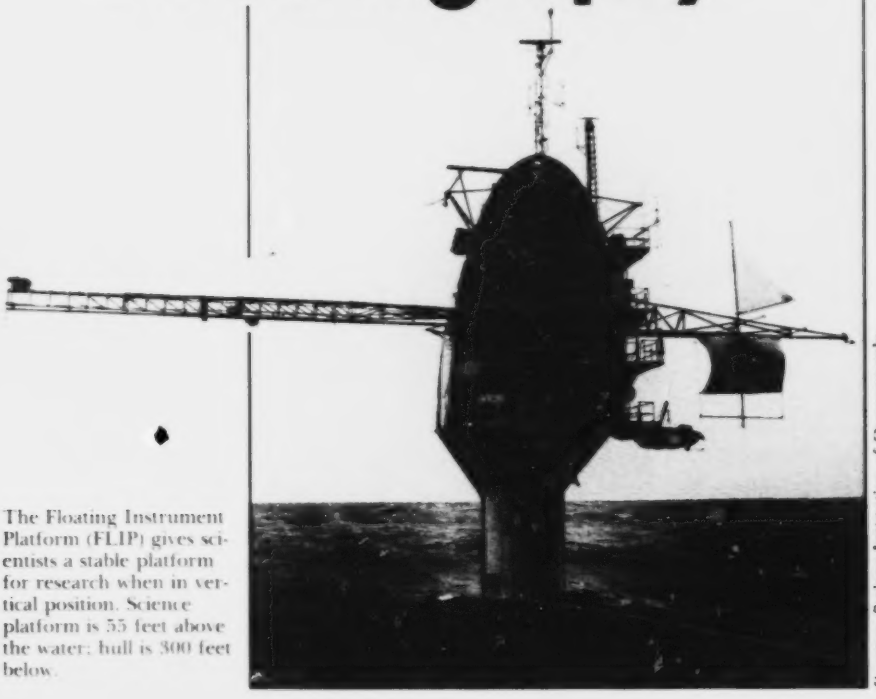
careers in Oceanography



The Floating Instrument Platform (FLIP) gives scientists a stable platform for research when in vertical position. Science platform is 55 feet above the water; hull is 300 feet below.

Courtesy Scripps Institution of Oceanography

Edited by
Charles D. Hollister
Dean and Senior Scientist
Woods Hole Oceanographic Institution
Woods Hole, Massachusetts

Courtesy Woods Hole Oceanographic Institution

eword

Sediment trap being launched from KNORR.

This booklet was prepared by practicing oceanographers to help college students in their search for professional direction. We have tried to transmit the complexity and the challenge of the oceans and our enjoyment of oceanography (whether at sea, in the laboratory, or behind a computer).

Oceanography uses all of the basic sciences to understand the behavior of the oceans and the ocean environment. The sea floor, oceans, atmosphere, and the way they interact affect life and its future on our planet. During this century we have obtained our first real understanding of the oceans. Our scientific vantage point ranges from the deepest parts of the seas to high in the atmosphere to outer space. The next century promises us the benefits of technology that will allow us to expand substantially the frontiers of oceanography.

Oceanography is a fast-moving field in which discoveries can be applied quickly to help solve important human and environmental problems and to exploit the many opportunities the oceans offer. Thus oceanographers can play a major role in the quality of life and

help provide a scientific basis for the laws which safeguard it. In oceanography, the interweaving of physical, chemical, geological, and biological disciplines is a complex and challenging one.

For you, the student considering oceanography, we point out some frontiers of current research, describe five major subfields of oceanography, outline the necessary undergraduate preparation, suggest how to approach graduate work, and discuss career prospects.

If you are interested in an oceanography career but don't yet know enough about oceanography to make a definite commitment, you should contact the Education Chairman of the Ocean Sciences Section, American Geophysical Union, 2000 Florida Avenue, N.W., Washington, DC 20009.

frontiers

Courtesy Woods Hole Oceanographic Institution

One of the largest academic research vessels, RV KNORR (245 ft), operated by Woods Hole Oceanographic Institution

Modern oceanography is only about one or two generations old. Although its original pioneers are now retiring, a frontier still exists: A new generation of oceanographers is having a dramatic impact on the science and promises to continue to do so for a long time to come.

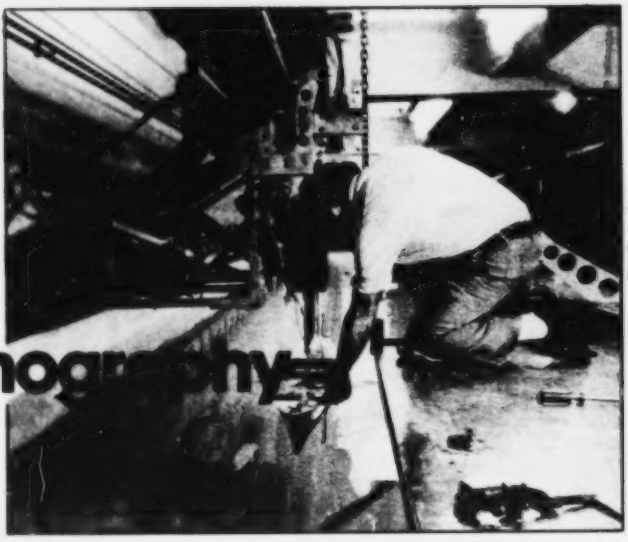
At present our capability to predict the short-term

dynamics of the oceans is low. For example, we cannot predict with much accuracy most scales of ocean motion, where pollutants will travel, or their rate of spreading and dilution. Vertical stirring of ocean waters is thought to be much slower than horizontal stirring, but quantitative predictions still elude us. These uncertainties have obvious implications for problems such as hazardous-waste disposal and the management of commerical fisheries. The use of space age technology and remote sensing by oceanographers is rapidly advancing our understanding of the oceans, but these new methods bring new problems to light while helping to solve the old.

Vents of very hot water, rich in nutrients and minerals and surrounded by previously unknown organisms, were recently discovered in the floor of the deep sea. This finding of rapidly growing bacteria at temperatures well in excess of 100°C has implications for fields from exobiology to industrial microbiology. It is having profound effects on our ideas about the history and composition of ocean waters and about the necessity of sunlight for life-giving processes and even about evolution. Some speculate that life may have begun in the lightless depths of the sea.

The processes by which vast amounts of sediment are redistributed over the deep sea floor, apparently by very high energy, near-bottom, oceanic storms is another puzzle. It happens, but why? Is it related to surface water motions? On another issue, what relentless forces have moved vast "plates" of the earth over its surface and regenerated the crust of the ocean basins? These are just a few examples of basic research problems that need to be solved.

careers in oceanography



Courtesy Department of Ocean Engineering, Massachusetts Institute of Technology

Tow tank for ship model experiments.

Some oceanographers will naturally go to sea on research vessels in order to obtain the information needed to solve their research problems, while some will use certain oceanographic data without going to sea. Others will obtain their data in the form of signals transmitted from satellites, then stored on magnetic tapes, and read by computers; still others will use the computer for modeling idealized situations. This modeling exercise is often one early step toward determining which data are actually needed for solving a particular problem. What all oceanographers seem to share is an intense commitment to research, an ability to extract the maximum information from any project, and the drive and confidence to complete tasks they initiate.

There are four major sectors of employment for people with training in oceanography: academics, private industry, consulting, and government. Academic positions involve varying proportions of teaching and research; the teaching salary is covered by the institution while research is supported by grants and con-

tracts received by the scientist. Academic positions offer the most freedom to control personal time and direction of research, but pay less than other jobs. Industry jobs usually offer the highest salaries, but time and research activities are more closely constrained. Consulting also pays well, but requires a high investment of energy and time to generate and complete projects, especially if one is self-employed. Finally, federal or state employees generally do both applied and basic research, much of it involving the synthesis of published data into reports. They tend to have more job security, with intermediate salaries.

A bachelor's degree in any of the basic sciences will allow you to obtain a job as field or lab technician or research assistant. The master's degree is sufficient for entry to consulting, industry, and some government jobs. A doctoral degree is usually required for those who go into the academic field or become high-level administrators in the other sectors.

Today the greatest demand is for geological/geophysical and physical oceanographers, ocean engineers, and chemical oceanographers. Currently, biological oceanographers are in less demand. Future career conditions cannot, however, be predicted with any certainty. Between the beginning and end of your graduate school career, the scientific emphasis and job priorities may change; for example, when OPEC raised oil prices, the demand for geologists immediately rose. Society's need for information determines its demand for scientists with advanced training.

The following sections briefly survey each of the disciplines contained within the general field of oceanography and describe some of the necessary educational preparation.

the subfields of oceanography

Courtesy MIT/WHOI Joint Program in Oceanography

Graduate students working on a sediment transport experiment.

Marine Geology and Geophysics

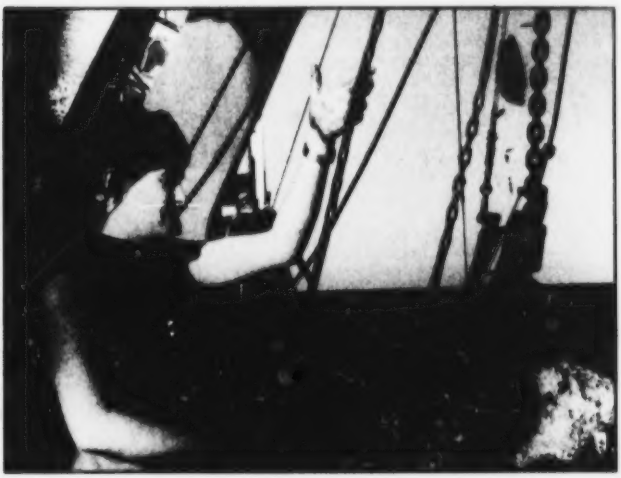
Marine geology and geophysics is one of the most interdisciplinary of the natural sciences. Fluid motions, chemical reactions, and living organisms all affect the sedimentary record of the seafloor. Strain, pressure, heat, and chemical gradients determine the composition and distribution of rock types and their interrelationships.

Marine geophysical research extends from the earth's center outward to the limit of the solid earth; the geophysicist, in contrast to the geologist, rarely sees or touches earth samples. Both propose and test hypotheses about the earth at and below the sea floor, aided primarily by remote sensing measurements. Both need training in mathematical methods and computer programming for data processing and model exercising. Geophysicists in particular search for anomalies such as unexpected strengths or weaknesses in the local gravity or magnetic field. They must use many pieces of information to narrow the range of possible

explanations for the formation of the earth and the processes acting on it. For example, the hypothesis that the "ribs" of the solid earth beneath the sea are formed at spreading centers and lost beneath convergent plate boundaries (the plate tectonic hypothesis) was made plausible by remotely sensing magnetic fields, by mapping sediment distributions through seismic reflection profiling, and by careful analysis of earthquake motions; the final confirmation, however, came from the bits of deep-sea sediment brought up by the drilling ship *Glomar Challenger*.

The geologist generally conducts research on the tectonic, volcanic, and sedimentation processes that determine the shape and structure of the sea floor from the continental shelf to the deep ocean. The geologist also strives for an understanding of the fossil record, which can reveal historical changes in climate and oceanic environment caused by the shifting of continent and ocean over the earth's surface. The principles of structural geology are applied to direct and remote observations of the sea bed, rock samples are analyzed, and the remote sensing methods of geophysics are employed.

Geologists are now giving special attention to the di-



Courtesy Lamont-Doherty Geological Observatory

Graduate student launching deep sea piston core.

Courtesy Woods Hole Oceanographic Institution

Oceanographers taking mud samples from box core.

vergent plate boundaries which are foci for release of the earth's internal heat and where material from deep within the earth is brought to the sea floor. These localized but intense flows of heat and mass from the earth's interior into the ocean waters are now recognized as necessary ingredients for economically valuable sea floor mineralization. The physical, chemical, microbial and geological processes of this newly discovered alchemy on the sea floor are only beginning to be understood, and they present a goal for interdisciplinary research.

Another and perhaps more immediately practical subfield is the geology of estuarine, coastal, and continental shelf areas—the largely storm wave and tide influenced edge of the sea. Vast sums of industrial and government monies are spent on coastal problems with often very futile, and even damaging, results. As a result there is both a growing need and a growing demand for more experts in coastal research.

While the fields of geology and geophysics are often considered separately in some institutions, the most successful geoscience researcher strives to maintain a

Courtesy Lamont-Doherty Geological Observatory

A student recording thermal conductivity from a deep sea core.

multidisciplinary perspective. An impressive set of marine geological and geophysical research tools (for example, the hydraulic piston core) has only recently emerged and promises to open up a new scale of seafloor investigations.

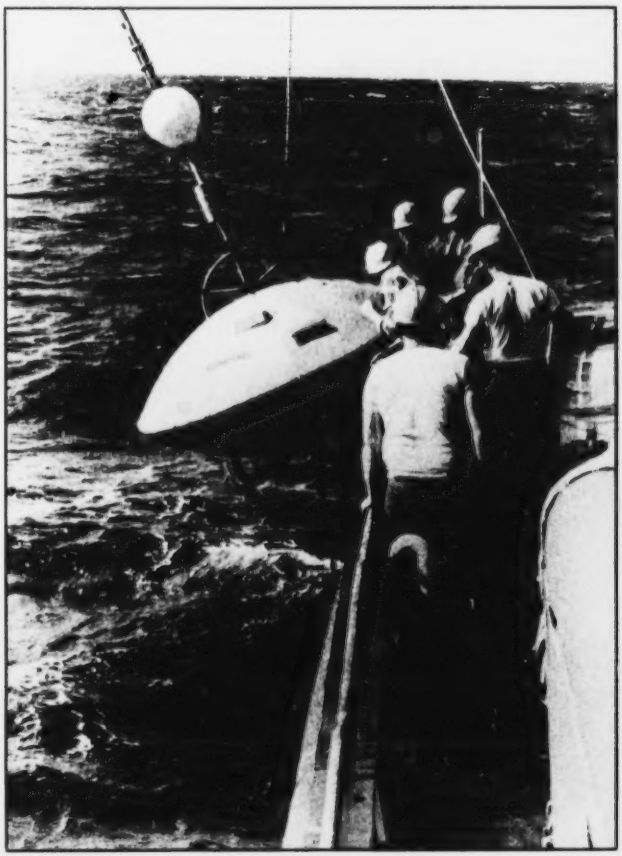
Oceanographic Engineering

The increasing sophistication of oceanography, especially within the last decade, has led to an unprecedented demand for special engineering knowledge and skills. The public, government, and industry are interested in the oceans—their resource potential, their use, and their defense. The field of ocean engineering has evolved in response to these urgent concerns. It is a complex hybrid of many of the classical engineering disciplines such as electrical, mechanical, civil, chemical, and marine engineering as well as naval architecture. Its challenging problems require creative combinations of a wide range of ocean science and engineering principles.

Some ocean engineers apply their talents to instrument design in order to measure physical processes

that may answer basic scientific and engineering questions about the ocean environment. Mechanical, electrical, acoustical, and optical techniques, as well as computer and signal processing algorithms, are required to obtain and interpret measurements. The equipment must function in the salty and corrosive ocean, an environment much more hostile than outer space.

Space age technology transferred to ocean engineering is leading to fundamental breakthroughs. For example, new measurement systems employ earth satel-



Courtesy Woods Hole Oceanographic Institution

A digital buoy system for recording sound transmission is brought aboard.

lites to transfer data from unmanned instruments located in the ocean. These instruments lead to new knowledge and open up many exciting opportunities for ocean engineers.

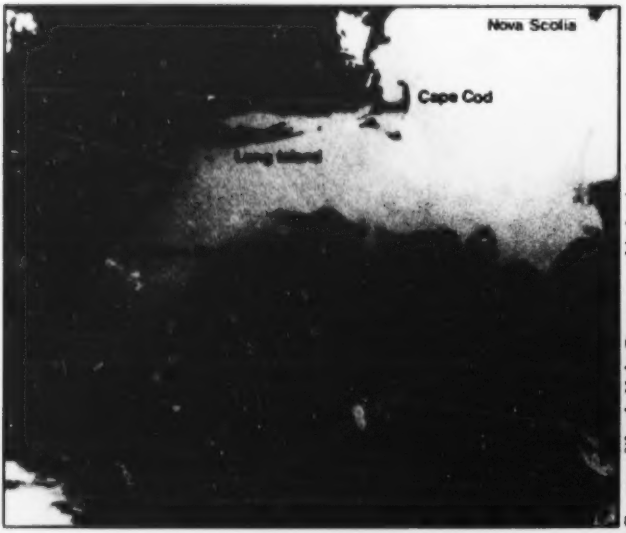
With the rapidly increasing exploitation of ocean resources, engineers are currently planning systems that could generate electrical power by taking advantage of the temperature differences between ocean surface and bottom, or by using tide and wave energy. Systems that operate under extremely high pressures will be needed for mining manganese nodules or polymetallic sulfides. Fossil fuels and minerals, needed by our growing society, must be obtained from the ocean safely, economically, and without environmental degradation. Designing offshore platforms and pipelines that will remain safe in winter storms and that will extract oil efficiently requires engineers versed in structural designing, chemistry, geology, sediment bearing strength, and oceanic environmental conditions such as fluid induced stress.

Engineers work hand in hand with science and commerce; their interests span the range from the theoretical to real applications. Ocean engineers fulfill these roles in the ocean environment; the demand for them is high and is expected to grow.

Physical Oceanography

The waters of the ocean move in grand, persistent currents like the Gulf Stream; in large eddies that resemble atmospheric weather systems; in wind-generated surface waves; in internal waves that carry momentum and energy with little surface disturbance; and in the millimeter-scale motions in which energy is dissipated. The task of the physical oceanographer is to learn how this complex system functions.

Evidence is obtained by shipboard instrument systems which yield a profile of the temperature and salinity vs. depth; and by moored instruments, such as the current meter, which can sit on a mooring for years storing measured values of currents and temperature for retrieval and analysis. Satellites are used not only to measure wind effects, currents, waves, and



Courtesy Woods Hole Oceanographic Institution

Satellite view of Gulf Stream and meanders defined by surface temperature.

temperature on a global scale, but also to relay data from drifting and moored instruments, and to provide signals used to determine the position of ships at sea.

Just 20 years ago none of these instruments or systems existed in practical form. But together with electronic engineers and radio scientists, physical oceanographers have developed new instruments that now yield a mass of information from which exciting discoveries will come.

Ashore, theoreticians work with the complex equations that govern fluid motion on the surface of a rotating sphere. They construct computer simulation models of the motion and energy flow, and some turn to laboratory models for guidance. Most are drawn back to direct physical evidence to check the reality of the ocean they interpret with pencil and paper, computer models, or rotating table.

Because most of the thermal energy stored in the ocean-atmosphere system is held in the upper few hundred meters of the ocean, our weather depends on the process by which this energy is exchanged with the atmosphere. An understanding of these processes is

Courtesy National Oceanic and Atmospheric Administration

A chemist injects a sample of fatty acids into a gas chromatograph.

required to improve our predictions of climate and weather.

Ever increasing development of shorelines and continental shelves calls for better knowledge of storms and the violent wave systems they produce. The increased demand to use the oceans as sites for waste disposal has created a race against time to define the processes by which pollutants are spread. Understanding the physics of the ocean is vital in assessing the effects of pollution on the fish and marine mammals of the ocean.

Chemical Oceanography

Chemical oceanographers investigate the evolution of seawater and seafloor sediments and also the processes that contribute to their variability. They also seek to understand the extent to which the environment may be changed naturally, and by man, and study natural processes for clues to the origin of the oceanic crust. Input from rivers, reactions at the

boundaries of air and sea, and seawater and sediment, and the interaction of seawater and volcanic rock at spreading centers of the ocean floor are under investigation as chemists consider the processes taking place at major boundaries. The genesis and composition of the oceanic crust and its interaction with seawater is important to a basic understanding of the ocean system.

Over the past decade marine organic chemistry has become one of the fastest-emerging fields in the environmental sciences. Interest grows in the application of analytical techniques and theories of organic chemistry to the environment, prompted by the concern of industry, government, and the public about chemical effects on life. Efforts to deal with the problem of toxic wastes have expanded from the worry of the 1960's about petroleum spills and pesticides to the passage by Congress in 1977 of the Toxic Substances Control Act. Both the chemical industry and government have become acutely aware of the need for chemists familiar with the environmental sciences. Work on the fluxes of organic carbon includes determination of the amount

Courtesy Woods Hole Oceanographic Institution

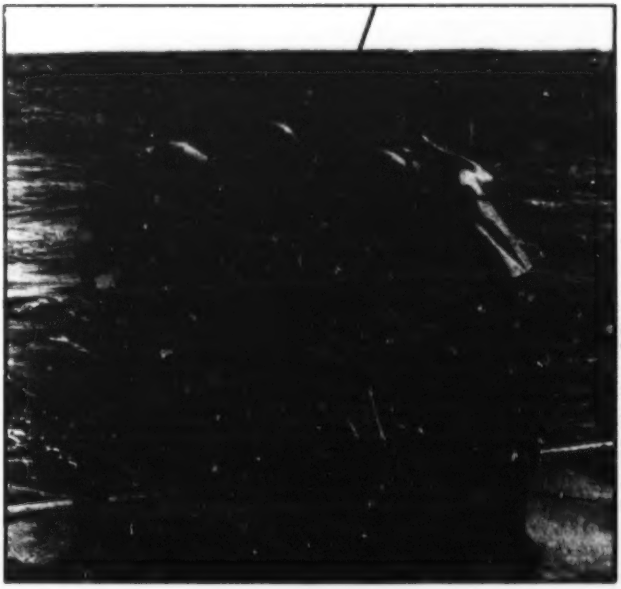
Graduate student takes water samples for chemical analysis.

of organic carbon produced in surface waters, the distribution, nature, and biogeochemistry of specific organic compounds in the marine environment, and studies of processes responsible for formation and diagenesis of organic matter in sediments. Another exciting development is the recent expansion of studies on chemical communication and the extraction of drugs from the sea.

While studying radioactive isotopes in the oceans, radiochemists have used the distributions of the natu-

Courtesy Woods Hole Oceanographic Institution

Launching a rosette of water samplers attached to an environmental measuring device.



Courtesy Scripps Institution of Oceanography

Students attach a plankton net to wire before lowering.

rally-occurring radioisotopes of the uranium-thorium series to estimate rates and verify models of mixing in the oceans and the sediment layers.

The role of the ocean in climate change, particularly with regard to substances such as carbon dioxide, nitrous oxide and fluorocarbons, is of far-reaching practical concern, as is the proposed mining of deep-sea metal deposits in the form of manganese nodules and polymetalic sulfides.

Biological Oceanography

Biological oceanography seeks to describe the biological processes that are active in the marine and bordering environments. The research of biological oceanographers is as diverse as the field of biology itself, ranging from ecology and systematics to biochemistry and physiology. In common with other branches of biology, the appreciation of chemical and physical

influences on biological events is an integral part of how life is perceived.

One of the challenges in biological oceanography is to compare the results of observations on individual organisms and laboratory experiments with patterns obtained from field studies and oceanographic cruises. Microbiology, planktonology, benthic biology, salt marsh and estuarine ecology, cell biology, physiology, biochemistry, animal behavior, and aquaculture are all applied to the study of biological processes in the world ocean. Questions under investigation include factors influencing the distribution patterns of many marine organisms; physiological, behavioral, and biochemical adaptations of species to variations in food, temperature, pressure, and light; food chain dynamics,

Courtesy Lamont-Doherty Geological Observatory

Oceanographer launching large volume water sampler for suspended sediment and radon studies.

Courtesy Woods Hole Oceanographic Institution

Graduate student collecting suspended sediment from glacial melt water off Spitzbergen.

especially with regard to nutrient cycling and the initial steps of chemical energy fixation. Marine policy issues are also considered as they relate to pollution, waste disposal and fishery management. Thus, there is room in biological oceanography for research ranging from the most basic to the most applied.

The ocean offers several environmental regimes that are quite different from those encountered on land, but similarities of marine to terrestrial systems are also to be expected. Biological oceanography employs the entire range of biological research techniques in a quest to explore and define the role of organisms in the marine environment. It offers many technological challenges in addition to requirements for adapting methodologies to oceanic problems. A strong background in fundamental fields of science is thus necessary before undertaking to study the poorly understood systems in the ocean. A multidisciplinary outlook is helpful in the investigation of marine research problems, but there is also a need for highly skilled specialists. The future of biological oceanography depends on advances in methods of data acquisition, sampling and culturing techniques, and parallel progress in all fields of biology.

Courtesy Woods Hole Oceanographic Institution

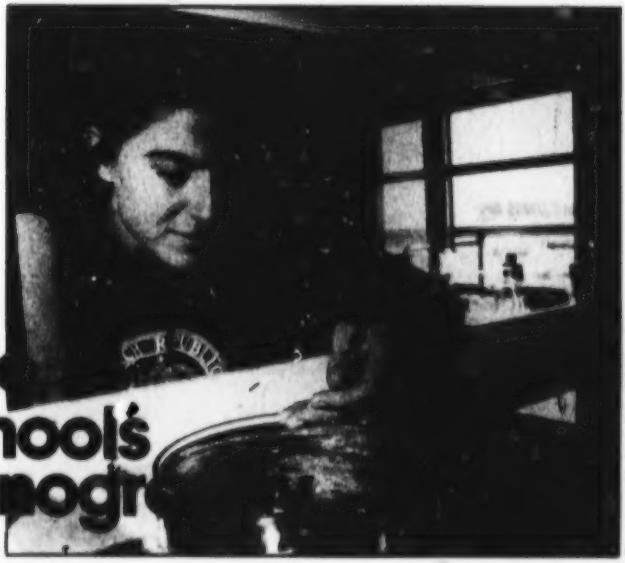
Oceanographer examining planktonic foraminifera (single celled animals) from a deep sea core

undergraduate preparation

The best undergraduate preparation for an oceanographer is rigorous training in applied mathematics, physics, chemistry, geology, biology, and engineering. Regardless of your choice of subfield, a strong background in mathematics and the basic sciences and some experience with computers is critical. Oceanography, by its very nature, is full of surprises; however, with a broad background in the basic sciences, you should be able to follow your scientific curiosity as it crosses the traditional barriers between disciplines.

Oceanography students reach graduate school with a variety of academic backgrounds. Within the first year or two, most will find some time to make up for deficiencies in their undergraduate work, but if the deficiencies are too great, the student will be advised to acquire the necessary background before entering graduate school.

graduate schools in oceanogr



Courtesy University of Miami

Graduate student checks progress of a tiny conch being reared in laboratory.

Graduate education in oceanography is concentrated in a relatively small number of schools. All welcome visitors, and a visit is the best way to learn about the important differences among schools. Come talk with a few professors, and meet the students. Find out what we oceanographers are like and how we spend our time. If you are unable to visit, write or call; we will be happy to answer your questions.

Some financial support and tuition waivers are generally obtainable, usually in the form of a research assistantship. The stipend varies from school to school; typically it is enough to support a single person but not a family. More-lucrative fellowships are given out

in certain fields for which the demand for graduates is strong, and the number of these fellowships is growing. Remember that these fellowships are available and should be applied for. They confer prestige on their recipients and also great freedom in choosing faculty advisers and research topics.

You should apply to several schools according to your ambitions, fields of interest, and academic record. Some schools offer more in some fields than others do; it is important to realize that centers of excel-

Courtesy University of Miami

A current meter buoy being recovered from the continental shelf

Courtesy University of Florida

Test tanks are used to improve net-towing efficiency for the fisheries industry.

lence can change as faculty members come and go. A visit to your chosen schools is definitely recommended before accepting an offer.

With these considerations in mind we have listed below those schools in the U.S. that have graduate-level marine science programs and that operate or use seagoing oceanographic facilities supported to a significant degree by federal funds. These schools are members of the University National Oceanographic Laboratories System (UNOLS), which collectively develops ship schedules for research cruises. In the list, we have noted with an asterisk those larger oceanographic institutions that grant doctoral degrees in all of the five subfields and who are members of Joint Oceanographic Institutions, Inc.* The other marine studies institutions in the list generally emphasize estuarine, coastal, or local research programs.

*JOI, Inc., is a consortium of the 10 largest oceanographic institutions organized to conduct major, multi-institution research programs, such as the Deep Sea Drilling Project.

University National Oceanographic Laboratories System

Institutions marked with an asterisk have Ph.D. programs in all fields of oceanography and are members of Joint Oceanographic Institutions, Inc.

Members

University of Alaska, Anchorage, AK 99504

University of Delaware, Newark, DE 19711

Duke University, Durham, NC 27706

*University of Hawaii at Manoa, Honolulu, HI 96822

Johns Hopkins University, Baltimore, MD 21218

*Lamont-Doherty Geological Observatory of Columbia University, Palisades, NY 10964

*University of Miami, Miami, FL 33149

*Oregon State University, Corvallis, OR 97331

*University of Rhode Island, Kingston, RI 02881

*Scripps Institution of Oceanography of the University of California, La Jolla, CA 92093

Skidaway Institute of Oceanography of the University of Georgia, Savannah, GA 31406

University of Southern California, Los Angeles, CA 90007

*Texas A&M University, College Station, TX 77843

*University of Texas Institute for Geophysics, Galveston, TX 77550

*University of Washington, Seattle, WA 98105

*Woods Hole Oceanographic Institution, Woods Hole, MA 02543

Associate Members

Bermuda Biological Station, Bermuda

Bigelow Laboratory for Ocean Sciences, West Boothbay Harbor, ME 04575

Brookhaven National Laboratory, Upton, NY 11973

Cape Fear Technical Institute, Wilmington, NC 28516

Chesapeake Biological Laboratory of the University of Maryland, Solomons, MD 20688

Dauphin Island Sea Laboratory of the University of Alabama, Dauphin Island, AL 36528

Florida Institute for Oceanography, St. Petersburg, FL 33701

Florida Institute of Technology, Melbourne, FL 32901

Hobart & William Smith Colleges, Geneva, NY 14456

Johnson Science Laboratory of the Harbor Branch Foundation, Ft. Pierce, FL 33450

Lehigh University, Bethlehem, PA 18015

University of Maine at Orono, Walpole, ME 04573

Marine Laboratory of Florida State University, Tallahassee, FL 32306

Marine Science Consortium, Wallops Island, VA 23377

Marine Sciences Institute of the University of California, Santa Barbara, CA 93106

Massachusetts Institute of Technology, Cambridge, MA 02139

Moss Landing Marine Laboratories, Moss Landing, CA 95039

University of New Hampshire, Durham, NH 02834

State University of New York at Buffalo, Buffalo, NY 14222

State University of New York at Stony Brook, Stony Brook, NY 11794

North Carolina State University, Raleigh, NC 27650

University of North Carolina at Wilmington, Wilmington, NC 28401

Nova University, Dania, FL 33004

Occidental College, Los Angeles, CA 90041

University of Puerto Rico, Mayaguez, PR 00708

San Diego State University, San Diego, CA 92115

Southeast Branch of the University of Connecticut, Groton, CT 06340

Virginia Institute of Marine Science, Gloucester Point, VA 23062

Walla Walla College, College Place, WA 99324

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Courtesy Lamont-Doherty Geological Observatory

Life at sea: science must go on!

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